

Anticipated Impacts of Soil Moisture Active Passive (SMAP) Mission Measurements on Hydrologic Applications

Remote Sensing and Hydrology
2010 Symposium (IAHS)
September 2010

The SMAP Science Definition
Team (SDT)



National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Talk Outline

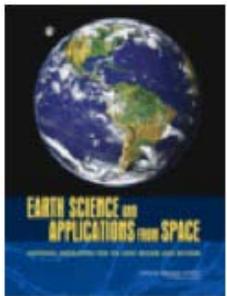
1. SMAP mission and the *Earth Science Decadal Survey*
2. Traceability of measurement requirements to hydrologic applications
3. Pathways of soil moisture influence on weather and climate
4. Applications to:
 - Drought monitoring and seasonal climate prediction
 - Water availability from snowmelt outlooks
 - Flood monitoring and forecasting
5. Data products and latencies



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Project/Mission Overview—Mission Context



US National Research
Council Report: “Earth
Science and Applications
from Space: National
Imperatives for the next

SMAP is one of four missions
recommended by the NRC “Decadal
Survey” for launch in the 2010–2013
time frame

- Feb 2008: NASA announces start of SMAP project
- SMAP is a directed-mission with heritage from Hydros
- Hydros risk-reduction performed during Phase A
(instrument, spacecraft dynamics, science, ground system)
Cancelled 2005 due to NASA budgetary constraints

Tier 1: 2010–2013 Launch

Soil Moisture Active Passive (SMAP)
ICESAT II
DESDynl
CLARREO

Tier 2: 2013–2016 Launch

SWOT
HYSPRI
ASCENDS
GEO-CAFE
ACE

Tier 3: 2016–2020 Launch

LIST
PATH
GRACE-II
SCLP
GACM
3D-WINDS



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Science Requirements

DS Objective	Application	Science Requirement
Weather Forecast	Initialization of Numerical Weather Prediction (NWP)	Hydrometeorology
Climate Prediction	Boundary and Initial Conditions for Seasonal Climate Prediction Models	Hydroclimatology
	Testing Land Surface Models in General Circulation Models	
Drought and Agriculture Monitoring	Seasonal Precipitation Prediction	Hydroclimatology
	Regional Drought Monitoring	
	Crop Outlook	
Flood Forecast Improvements	River Forecast Model Initialization	Hydrometeorology
	Flash Flood Guidance (FFG)	
	NWP Initialization for Precipitation Forecast	
Human Health	Seasonal Heat Stress Outlook	Hydroclimatology
	Near-Term Air Temperature and Heat Stress Forecast	Hydrometeorology
	Disease Vector Seasonal Outlook	Hydroclimatology
	Disease Vector Near-Term Forecast (NWP)	Hydrometeorology
Boreal Carbon	Freeze/Thaw Date	Freeze/Thaw State

Requirement	Hydro-Meteorology	Hydro-Climatology	Carbon Cycle	Baseline Mission	
				Soil Moisture	Freeze/Thaw
Resolution	4–15 km	50–100 km	1–10 km	10 km	3 km
Refresh Rate	2–3 days	3–4 days	2–3 days ⁽¹⁾	3 days	2 days ⁽¹⁾
Accuracy	4–6% **	4–6%**	80–70%*	4%**	80%*

(*) % classification accuracy (binary Freeze/Thaw)

(**) [cm³ cm⁻³] volumetric water content, 1-sigma

(1) North of 45N latitude



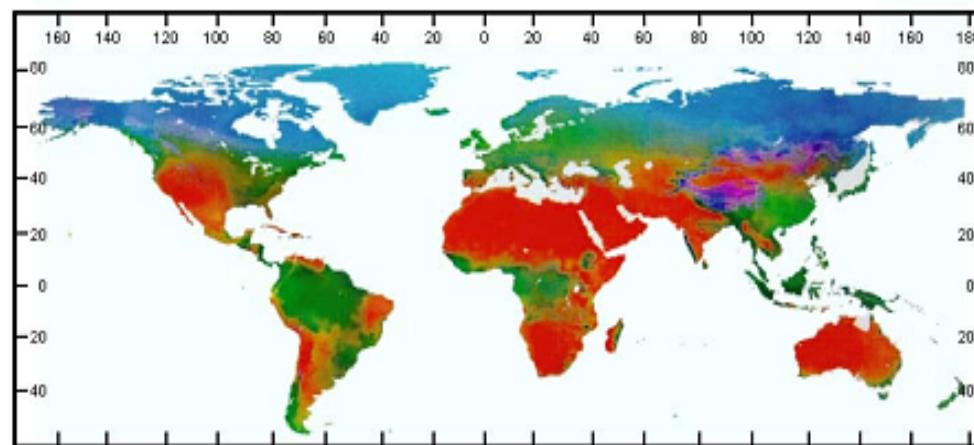
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Mission Science Objective

Global mapping of Soil Moisture and Freeze/Thaw state to:

- Understand processes that *link* the terrestrial water, energy & carbon cycles
- Estimate global water and energy fluxes at the land surface
- Quantify net carbon flux in boreal landscapes
- *Enhance weather and climate forecast skill*
- *Develop improved flood prediction and drought monitoring capability*



Primary Controls on Land
Evaporation and Biosphere
Primary Productivity

Soil
Moisture Freeze/
Thaw
Radiation

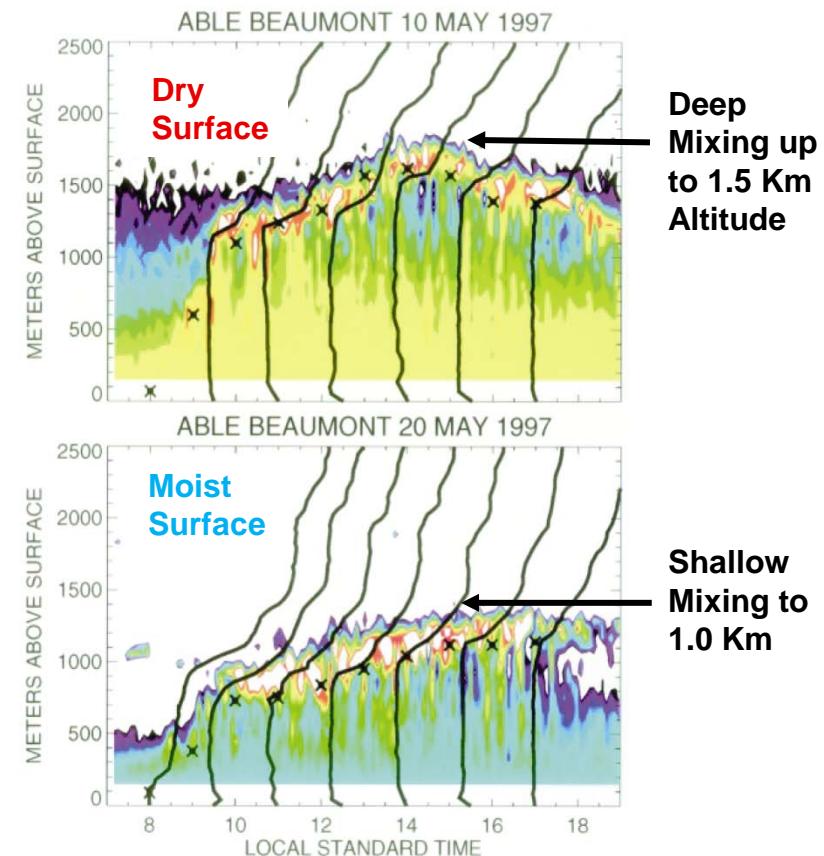
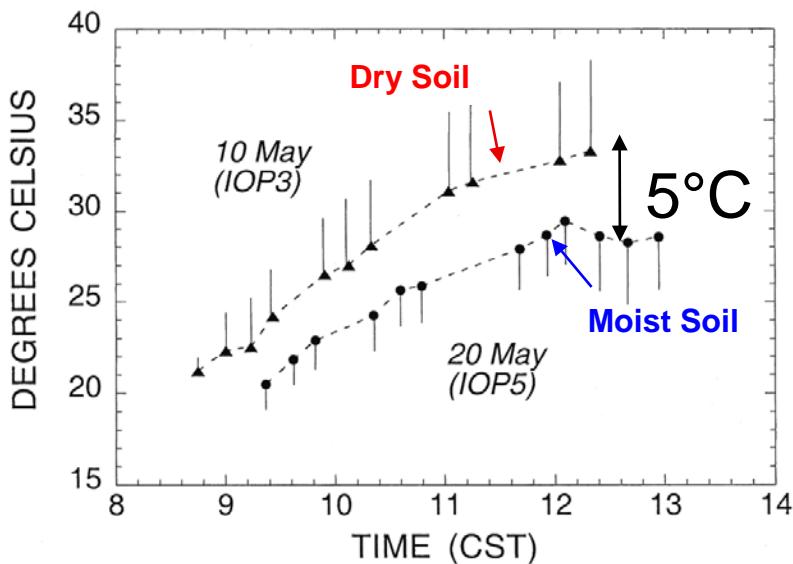


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Pathways of Land Surface Influence on Weather and Climate

May 10 Dry soil, clear, mild winds. ($LE \approx H$)
May 18 90 mm Rain
May 20 Moist soil, clear, mild winds. ($LE > H$)



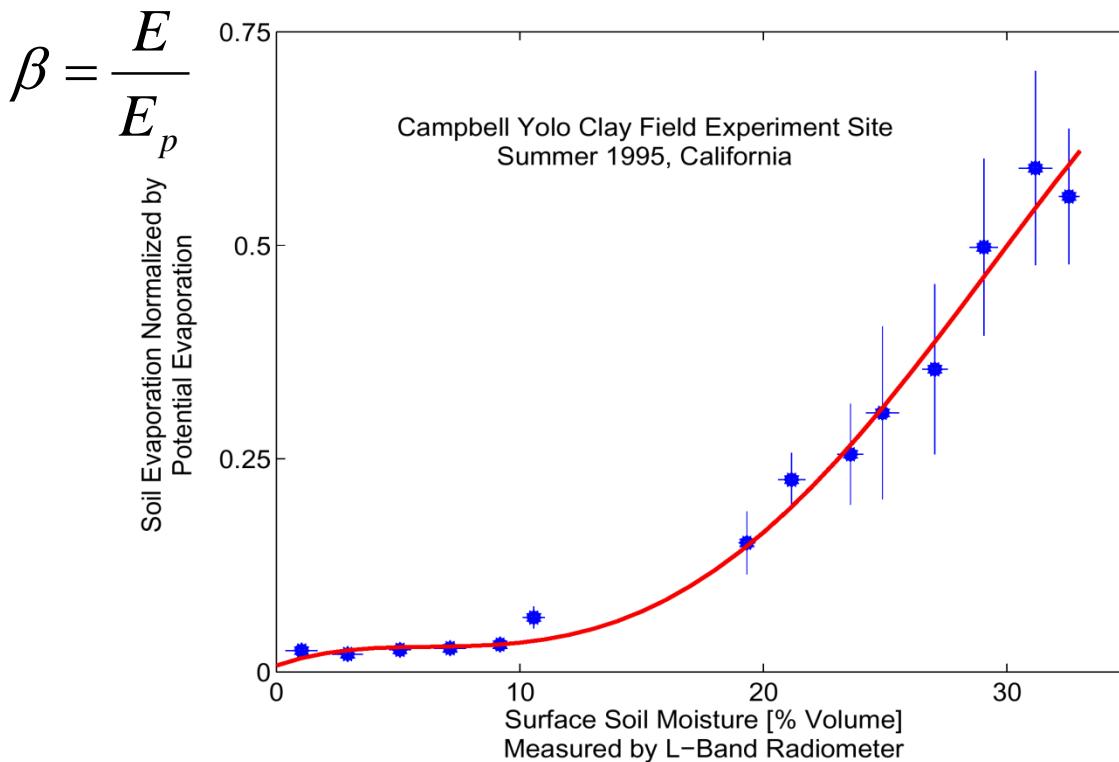
CASES'97 Field Experiment,
BAMS, 81(4), 2000.



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Key Determinants of Land Evaporation



Latent heat flux
(evaporation) *links* the
water, energy, and carbon
cycles at the surface.

Closure relationship, yet
virtually unknown.

Lack of knowledge of soil
moisture control on
evaporation causes
uncertainty in land surface
and atmospheric models.



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What Do We Do Today?

NOAH

model grid cell and

$$\beta = \left(\frac{\Theta_1 - \Theta_w}{\Theta_{ref} - \Theta_w} \right)^f \quad (7)$$

represents a normalized soil moisture availability term
where Θ_w is the wilting point and Θ_{ref} is the field capac-

CLM

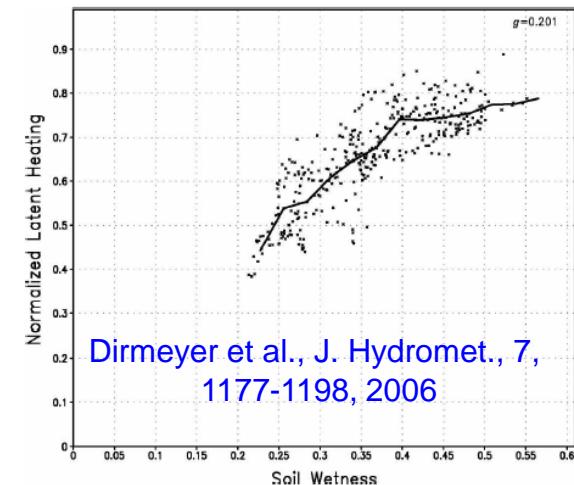
functional type and the soil water potential of each soil layer

$$\beta_t = \sum_i w_i r_i \geq 1 \times 10^{-10} \quad (8.10)$$

where w_i is a soil dryness or plant wilting factor for layer i , and r_i is the fraction of roots
in layer i .

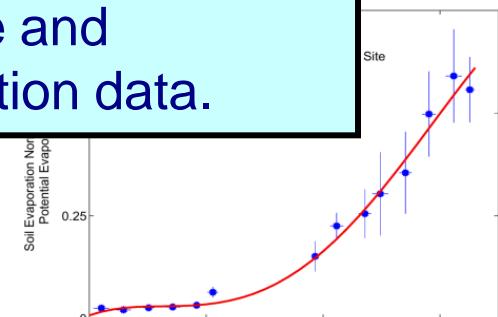
The plant wilting factor w_i is

$$w_i = \begin{cases} \frac{\psi_{max} - \psi_i}{\psi_{max} + \psi_{sat,i}} & \text{for } T_i > T_f \\ 0 & \text{for } T_i \leq T_f \end{cases} \quad (8.11)$$



Dirmeyer et al., J. Hydromet., 7,
1177-1198, 2006

Atmospheric model
representations of this
function are
essentially “guesses”,
given scarcity of soil
moisture and
evaporation data.





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Identification of Drought

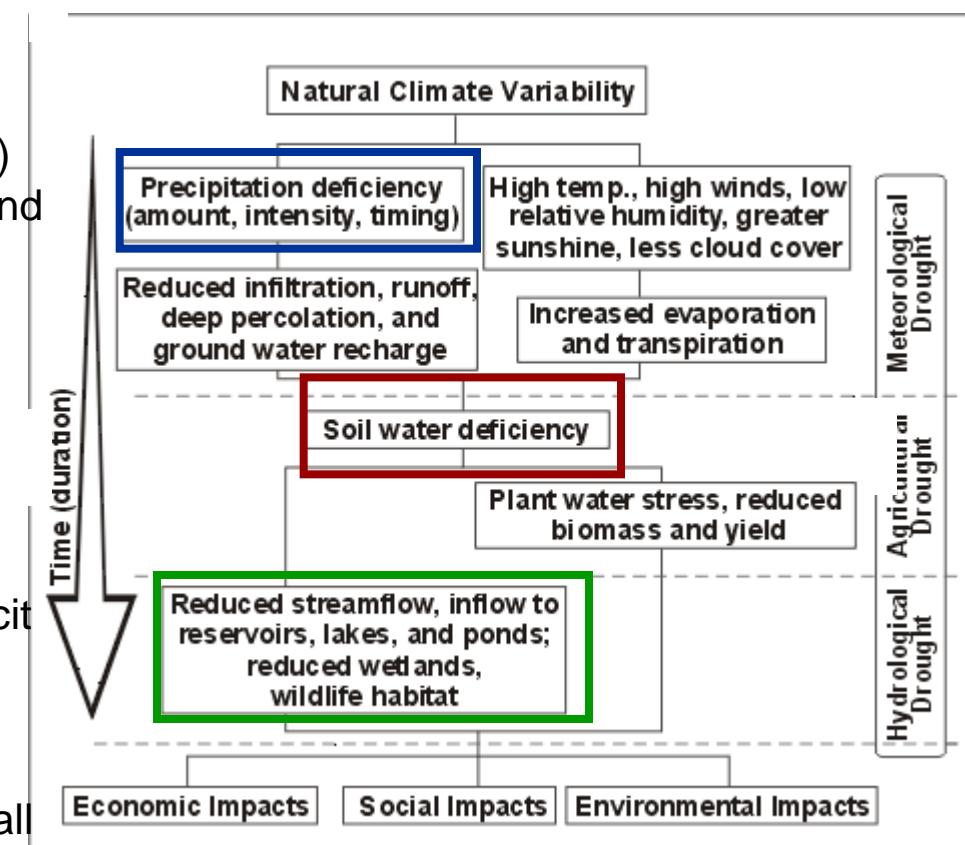
American Meteorological Society (AMS) Statement

Drought is often grouped into four basic types: 1) meteorological, 2) agricultural, 3) hydrological, and 4) socioeconomic.

Meteorological drought ... magnitude [and duration] of a precipitation shortfall

Agricultural drought is largely the result of a deficit of soil moisture...

Hydrological droughts are concerned with shortfall on surface or subsurface water supply... Rootzone, vegetation and streams response





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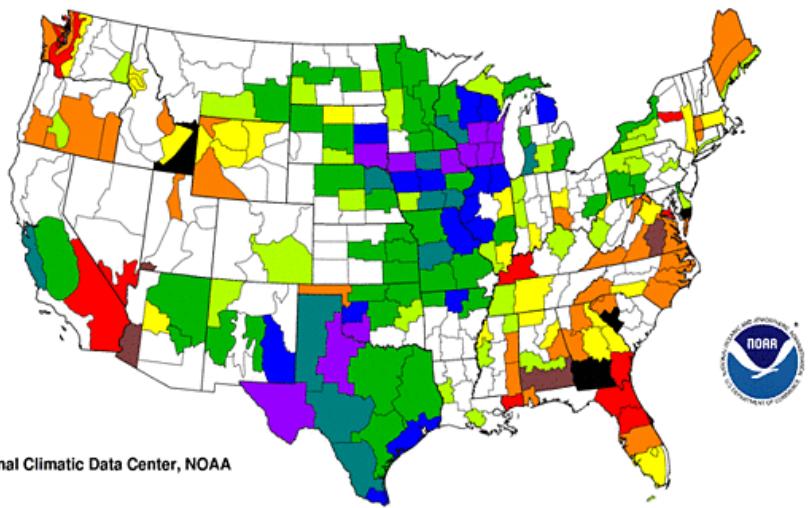
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Drought and Soil Moisture

Agricultural drought (deficit of soil moisture) cannot necessarily be inferred from precipitation deficit.

Standardized Precipitation Index
One Month

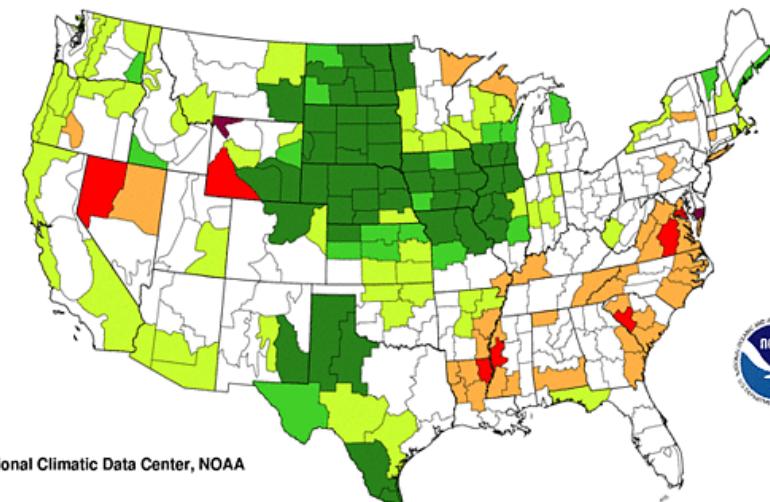
July 2010



exceptionally dry	extremely dry	severely dry	moderately dry	abnormally dry	near normal	abnormally moist	moderately moist	very moist	extremely moist	exceptionally moist
-2.00 and below	-1.99 to -1.60	-1.59 to -1.30	-1.59 to -0.80	-0.79 to -0.51	-0.50 to +0.50	+0.51 to +0.79	+0.80 to +1.29	+1.30 to +1.59	+1.60 to +1.99	+2.00 and above

Palmer Hydrological Drought Index
Long-Term (Hydrological) Conditions

July 2010



extreme drought	severe drought	moderate drought	mid-range	moderately moist	very moist	extremely moist
-4.00 and below	-3.00 to -3.99	-2.00 to -2.99	-1.99 to +1.99	+2.00 to +2.99	+3.00 to +3.99	+4.00 and above

The Standardized
Precipitation Index (SPI)
for July 2010.

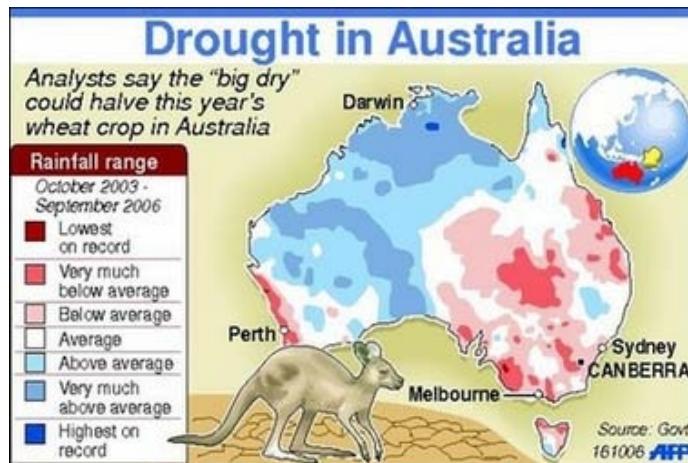
Palmer Drought Severity
Index (PDSI)
for July 2010.



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Role of Root-Zone Soil Moisture in Drought Duration and Climate Change Impacts



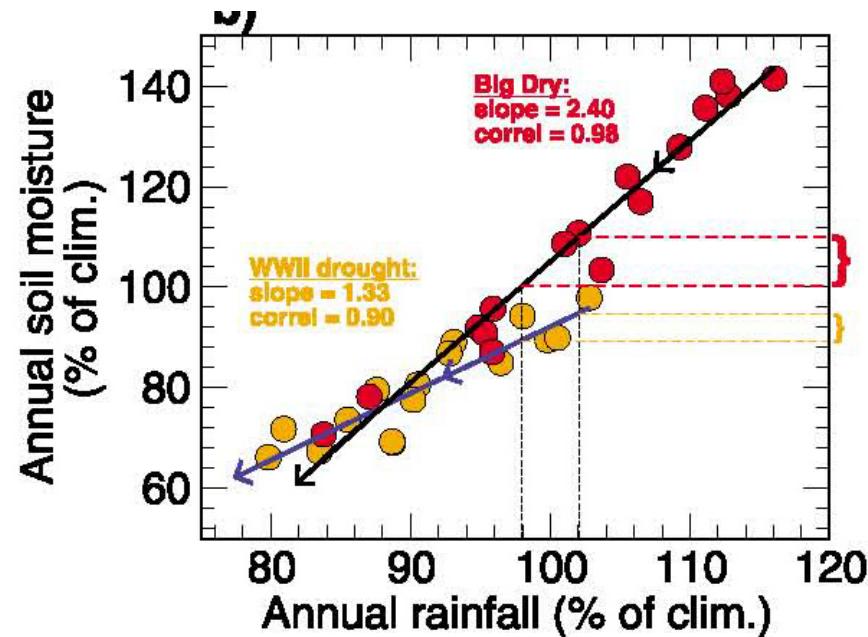
“Compared with the WWII drought, multi-year averages of rainfall and subsurface soil moisture during the Big Dry are not as low, but the sensitivity of soil moisture to rainfall decline is over 80% higher.

We show that a relationship exists between subsurface soil moisture variations and fluctuations of temperature not associated with rainfall over eastern Australia in all seasons, and over SEA in austral spring and summer. “

Root-zone soil moisture dynamics may contribute to prolonged drought conditions.

Conditions are similar to those expected under global change.

Cai et al., 2009: Rising temperatures depletes soil moisture and exacerbates severe drought conditions across southeast Australia, *Geophys. Res. Letters*, 36.

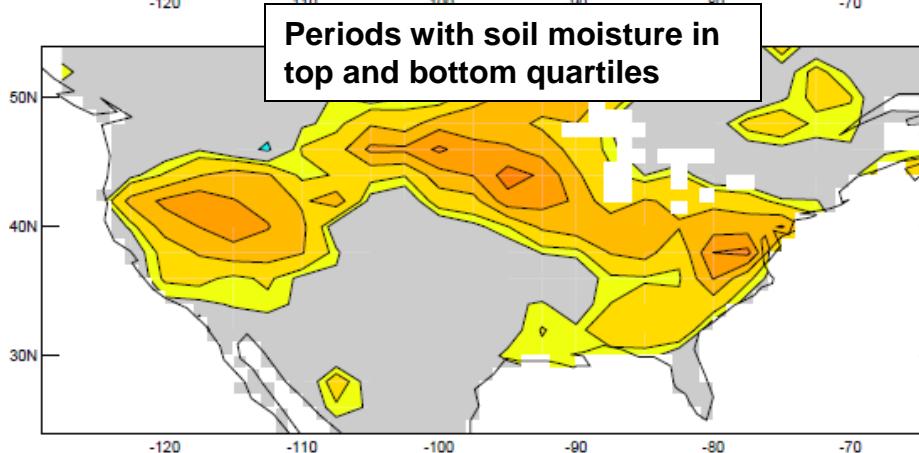
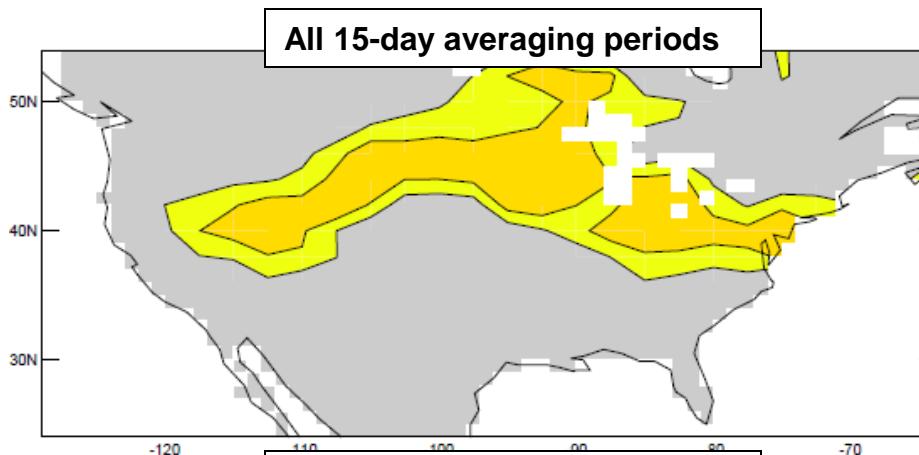




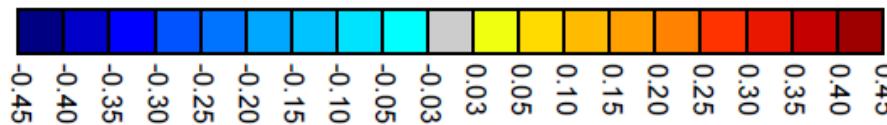
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Seasonal Climate Prediction



Temperature Forecast Skill, Days 31-45



Multi-model consensus view
of land contribution to air
temperature forecasts.

JJA Skill contribution at the
30-day lead (days 31-45).

From: Final Report of GLACE-2:
Quantifying the Effects of Land
Moisture Initialization on Precipitation
Forecasts (PI: Randal Koster, 2010)

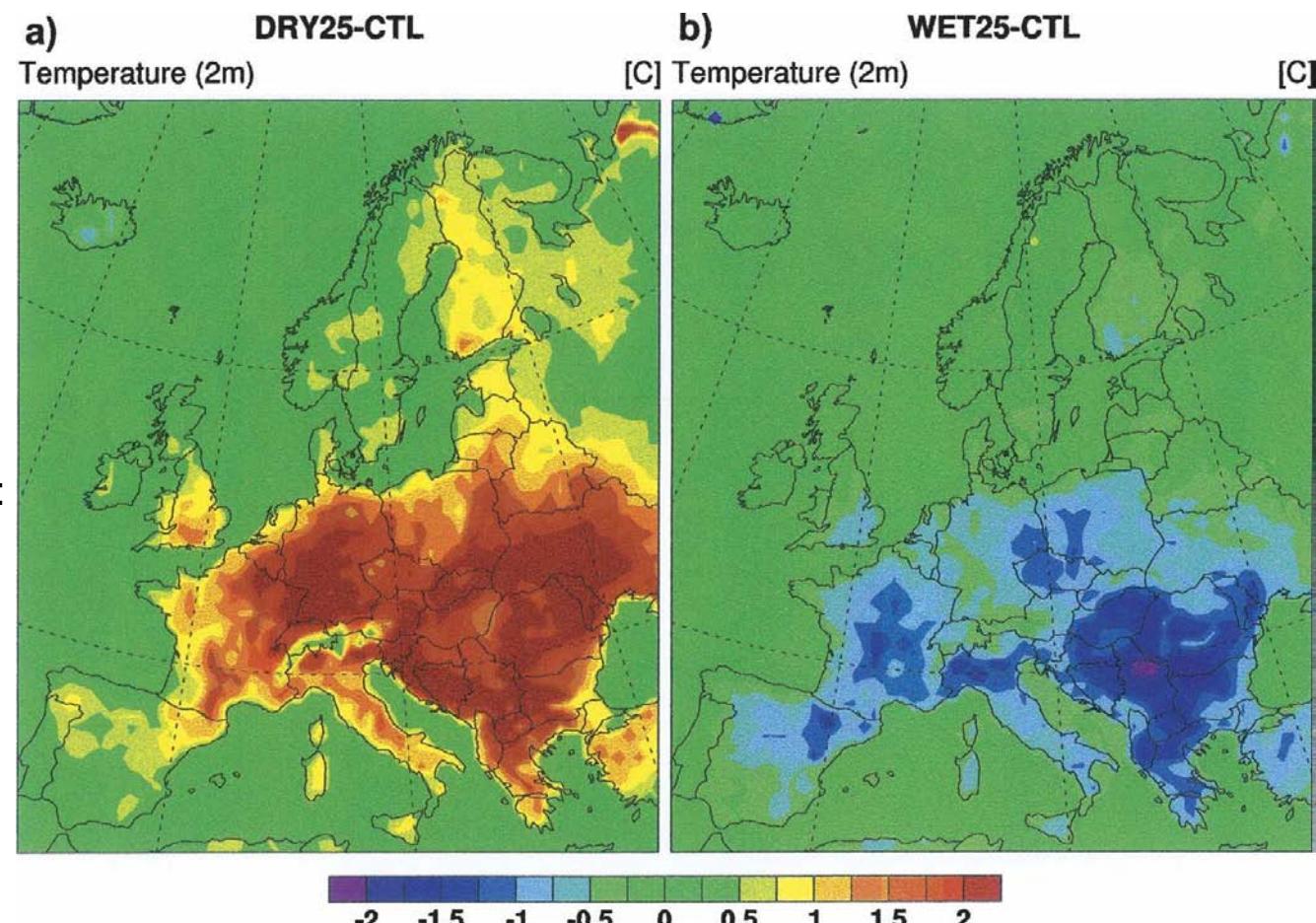


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Seasonal Climate Prediction

European heatwave cause
35,000 deaths,
New Scientist, Oct. 2003.



Seasonal Climate Prediction:
50 km Resolution
Initialize rootzone moisture



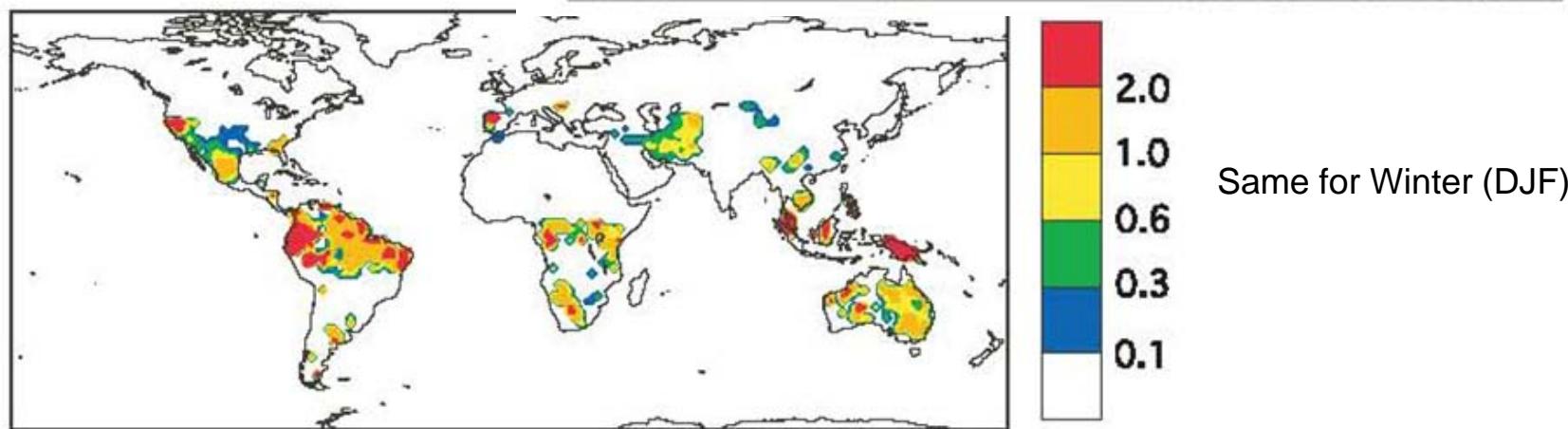
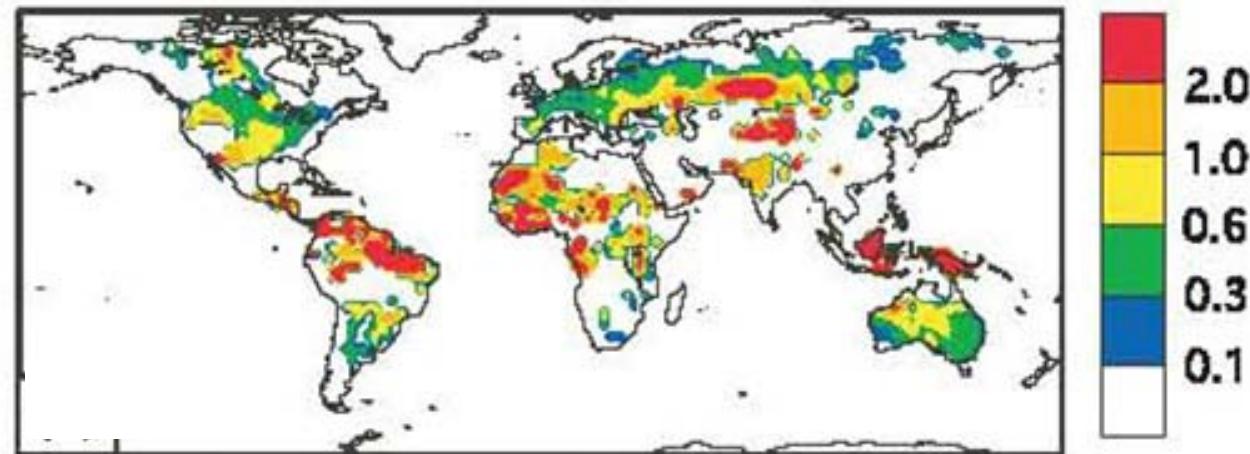
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Global Change and Water Cycle

Future Climate and Water Cycle: Soil moisture influence on precipitation intensifies the regional water cycle response to global change.

Mean Summer (JJA) soil
moisture feedback parameter on
precipitation among 19 IPCC
models [cm/month]



Global average monthly
precipitation over land is
~8 cm/month

Notaro, M., 2008: Statistical identification of global hot spots in soil moisture feedback among IPCC AR4 models, *J. Geophys. Res.*, 113.



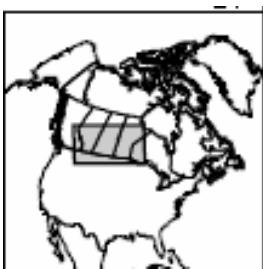
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Water Availability from Snowmelt

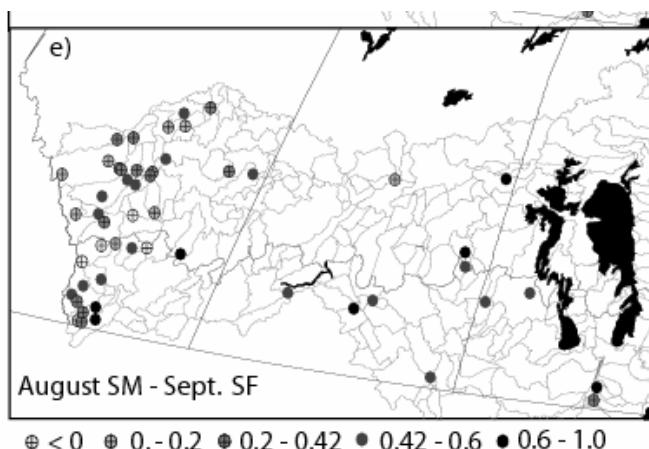
Soil moisture information can contribute skill to streamflow forecasts

Linear regression analysis examining observed
streamflow, snow, climate and soil moisture:

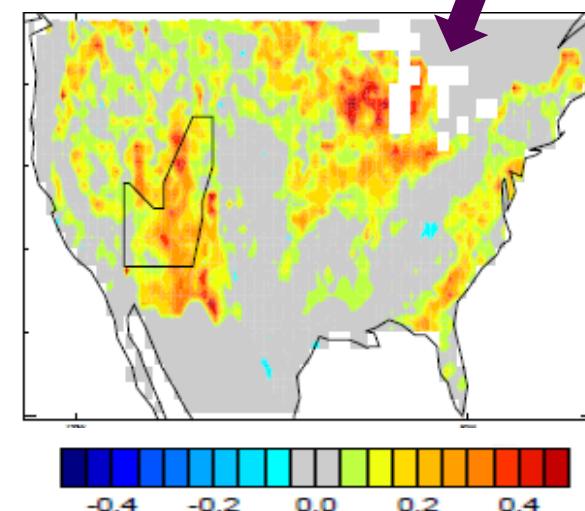


"This study demonstrates that available macroscale estimates of soil moisture have the potential to enhance streamflow prediction..."

(Berg and Mulroy, Hydro. Sci., 51, 642-654, 2006)



Contribution (r^2) of Jan. 1
soil moisture initialization to
MAM streamflow prediction.



Synthetic analysis showing where soil moisture initialization may improve streamflow prediction at seasonal timescales. Results are supported by available streamflow observations.
(Mahanama et al., in preparation)



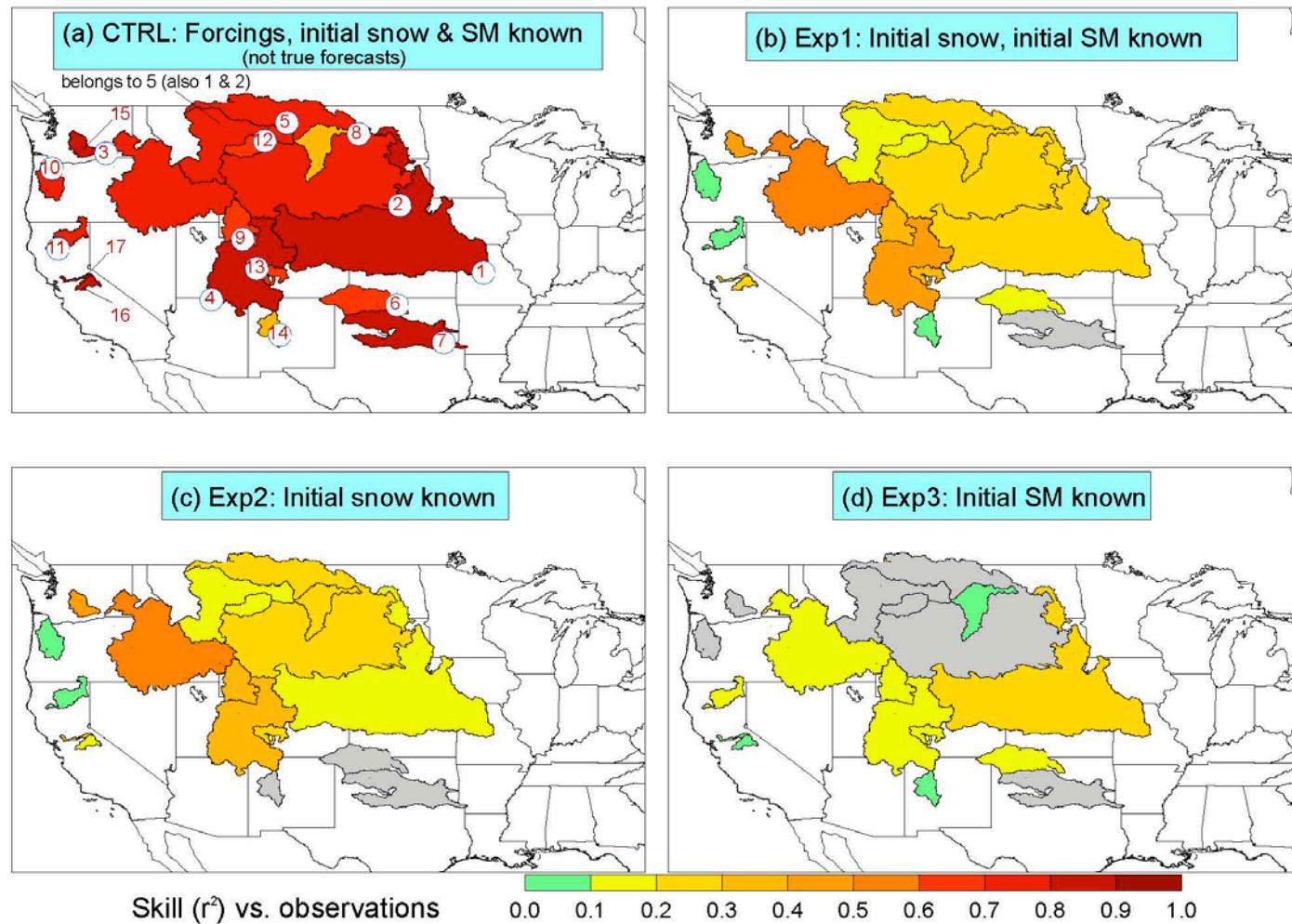
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Soil Moisture Information Enhances Water Resource Availability Predictions

Koster et al., 2010: Skill in streamflow forecasts derived from large-scale estimates of soil moisture and snow", *Nature-Geoscience*, in press.

May-July
streamflow
forecasts





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Flood Applications: The Forecast and Monitoring Chain

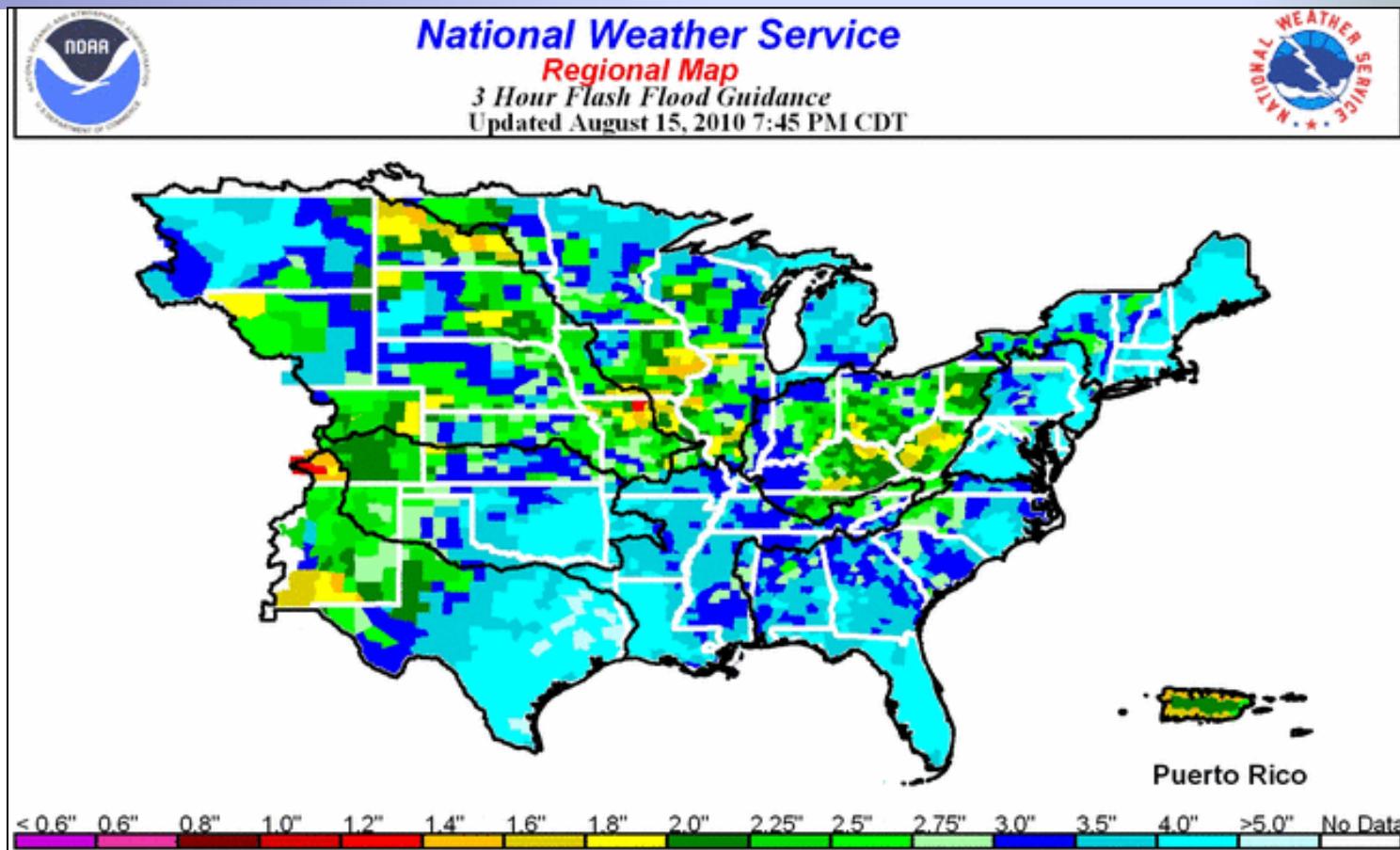
- 1) Characterization of pre-storm soil moisture
- 2) Accurate real-time rainfall monitoring (in large basins)
- 3) Numerical weather prediction of extreme rainfall
- 4) Monitoring inundation



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Characterization of Pre-Storm Soil Moisture



Current: Empirical soil moisture indices based on filtering precipitation time-series at county resolution (~50 km)

Future: Direct observations: SMAP at 10 km

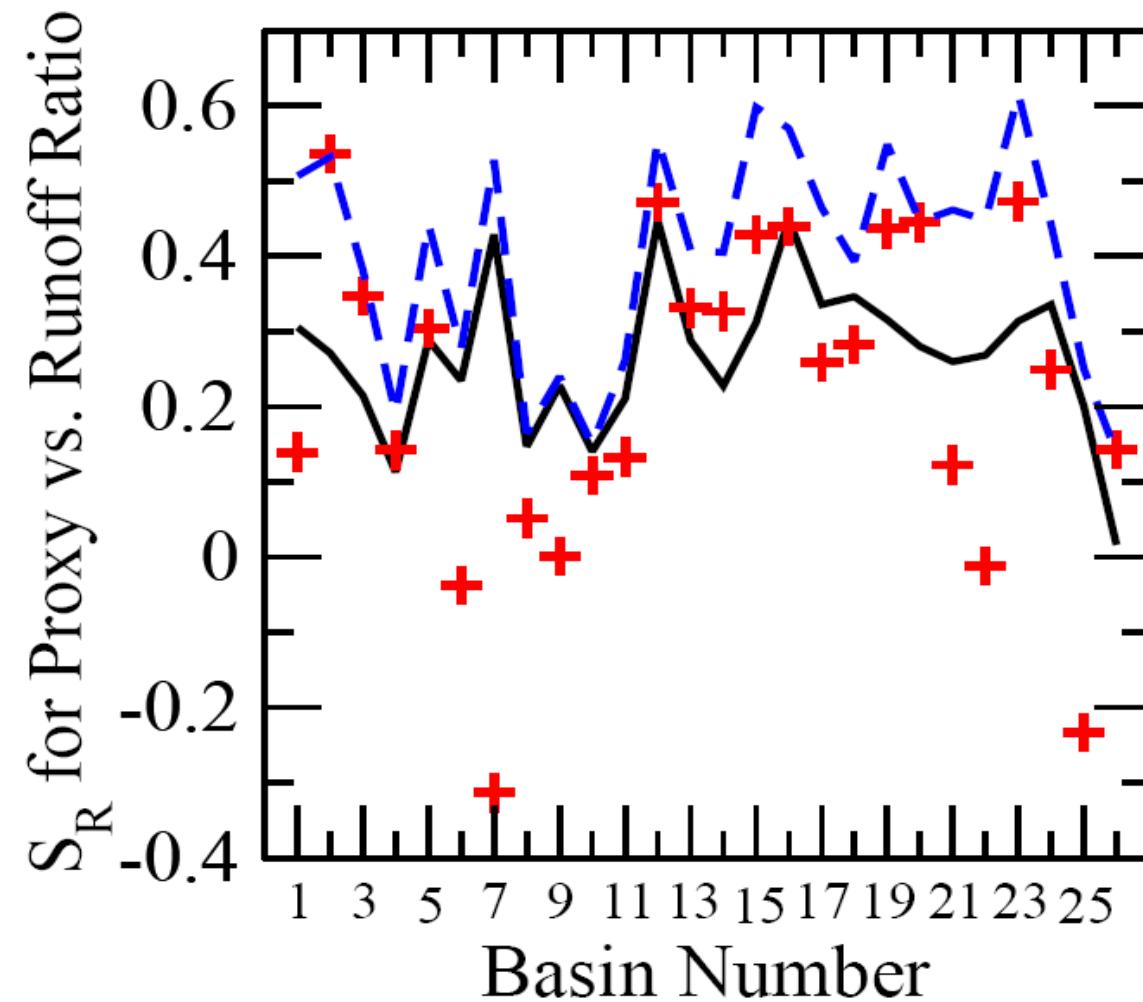


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Characterization of Pre-Storm Soil Moisture

- Red – Remote Sensing Only (TRMM TMI)
- Black – Model Only
- Blue – Remote Sensing/ Model KF Combined



($>30^2$ km 2 MOPEX Basins in Southern US)



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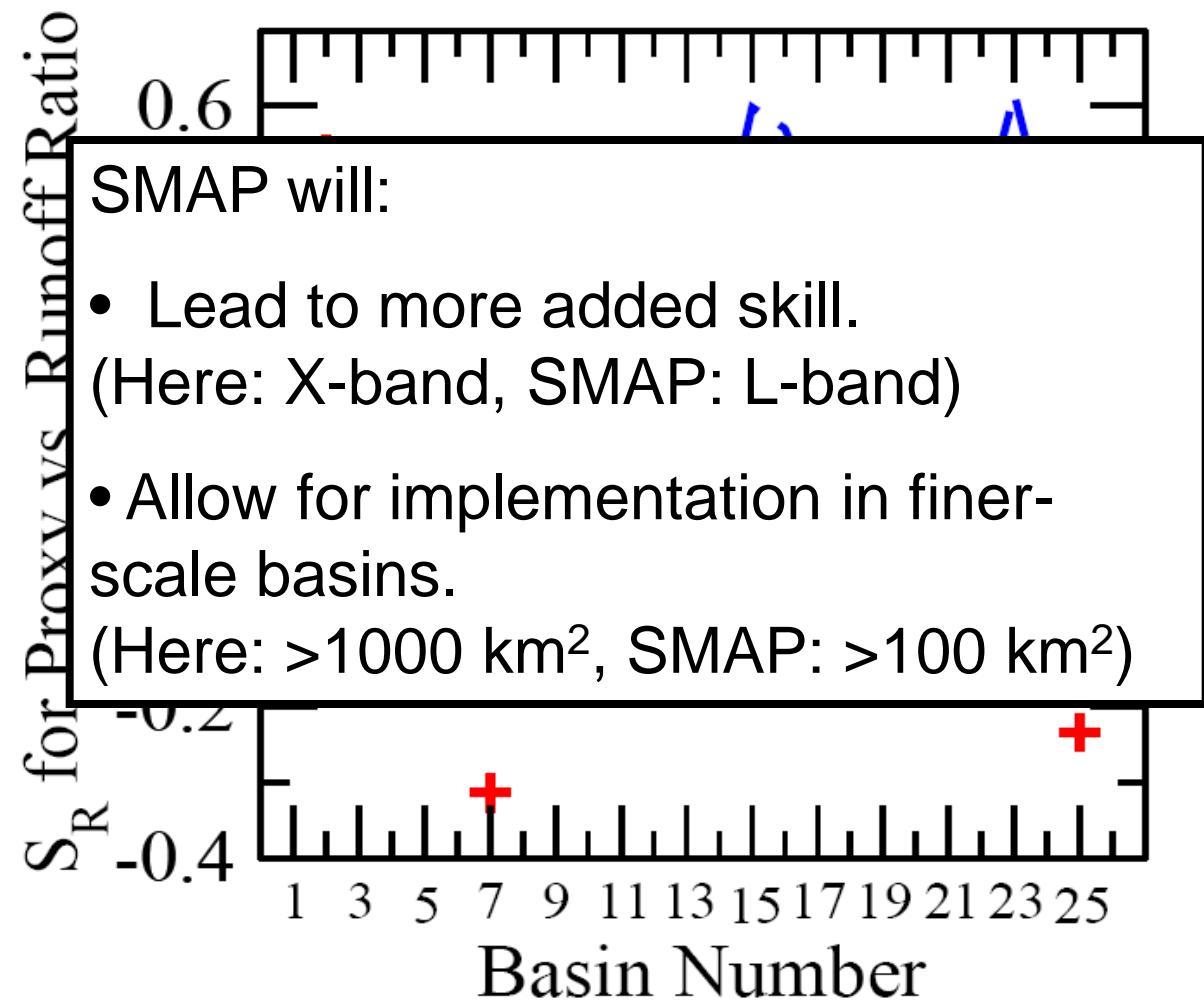
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Characterization of Pre-Storm Soil Moisture

Red – Remote
Sensing Only
(TRMM TMI)

Black – Model
Only

Blue – Remote
Sensing/ Model
KF Combined



(>30² km² MOPEX Basins in Southern US)

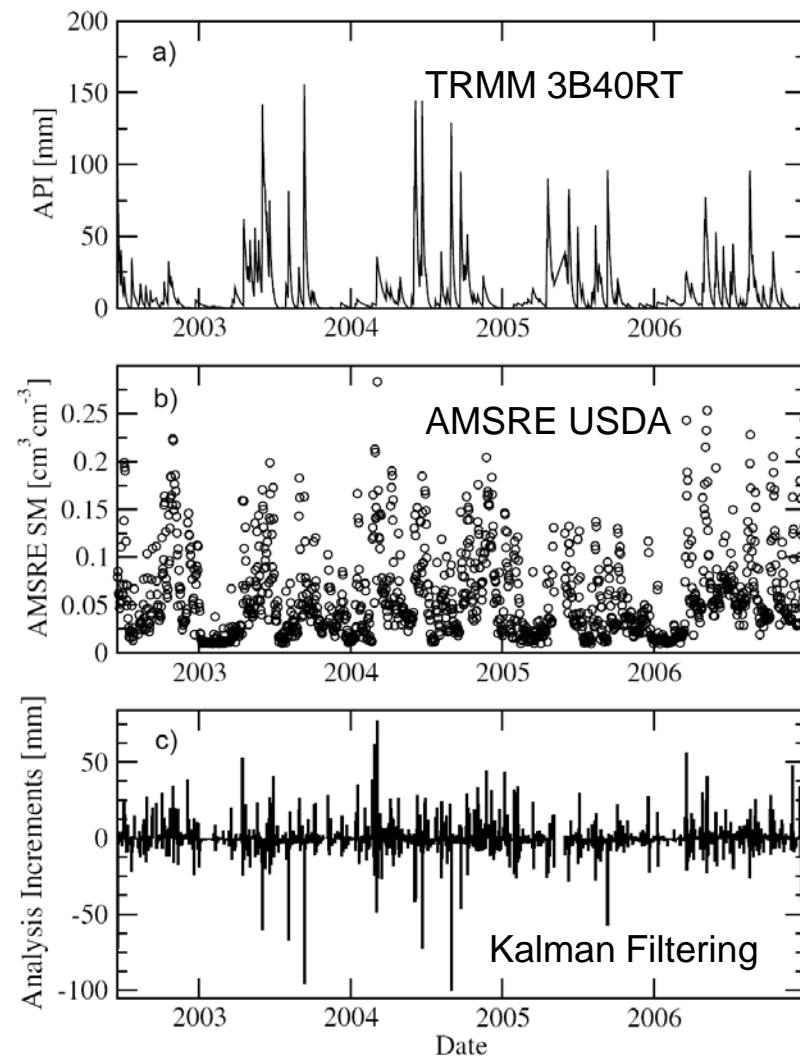
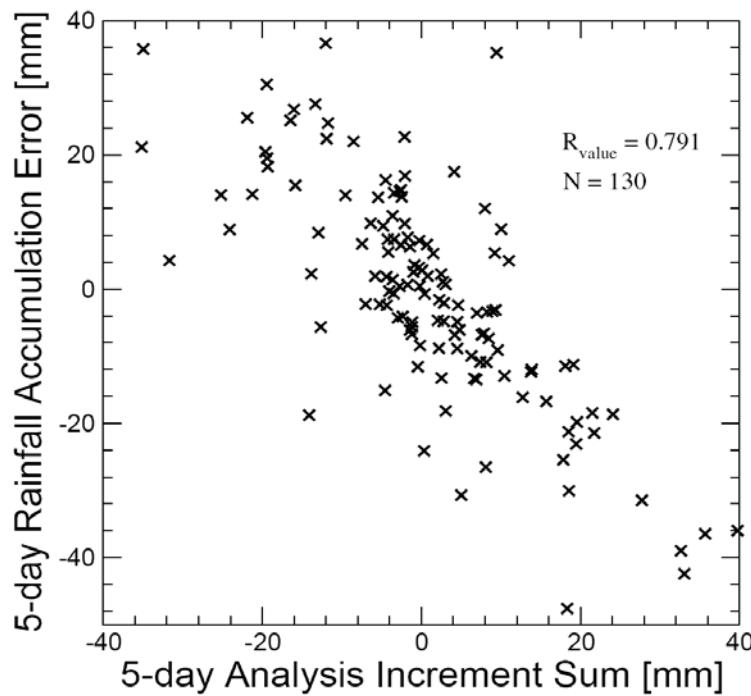


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Accurate Rainfall Monitoring

Crow et al. (2009), JHM, 10(1), 199-212.





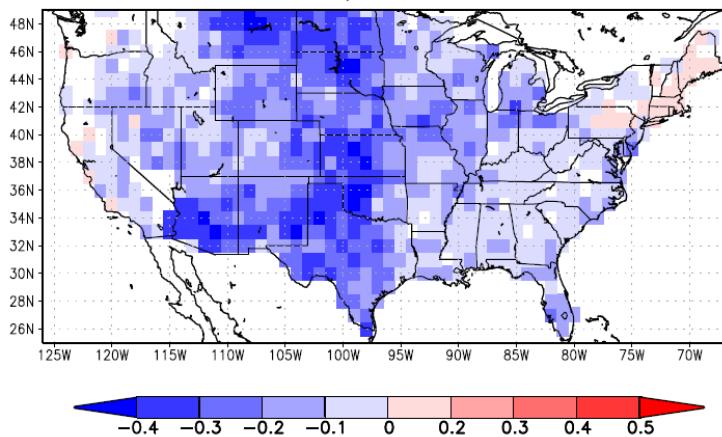
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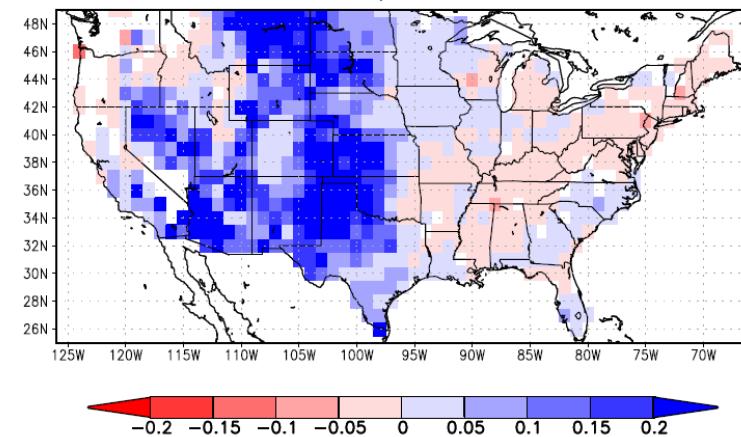
Accurate Rainfall Monitoring

Improvement in TRMM 3B40RT 3-day accumulation skill

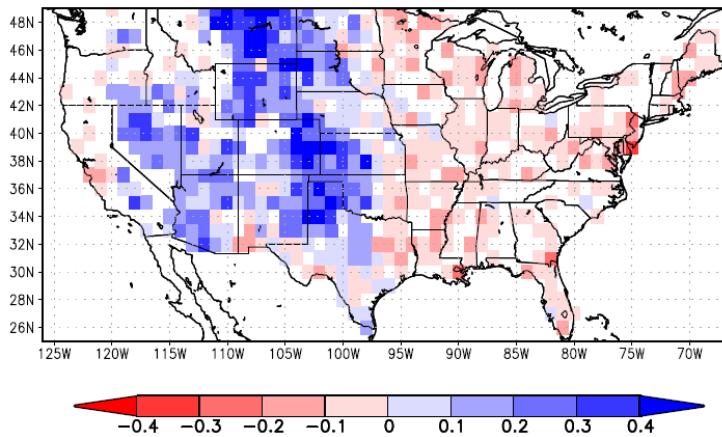
a) RMSE



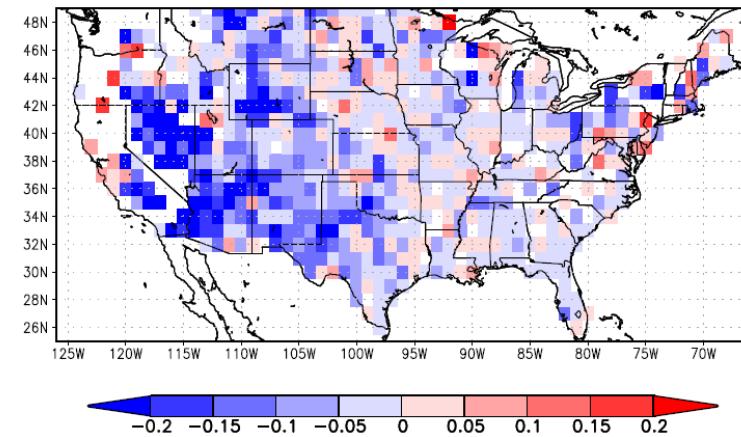
b) R2



c) POD



d) FAR





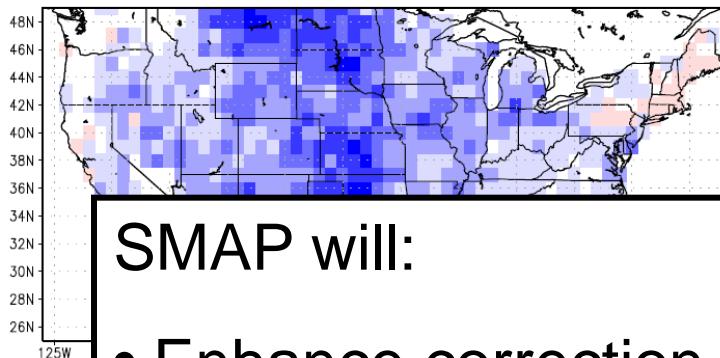
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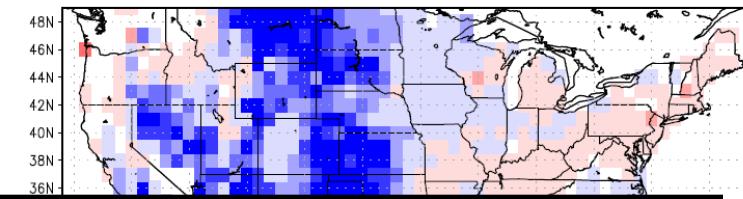
Accurate Rainfall Monitoring

Improvement in TRMM 3B40RT 3-day accumulation skill

a) RMSE

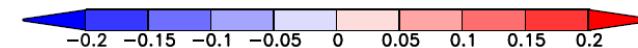
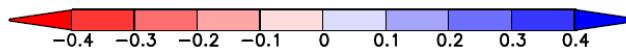
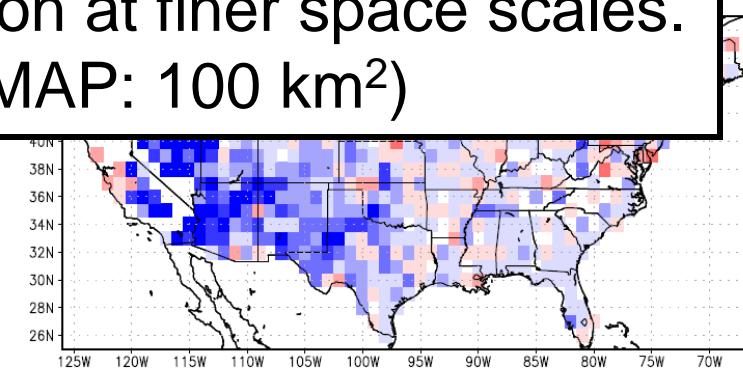
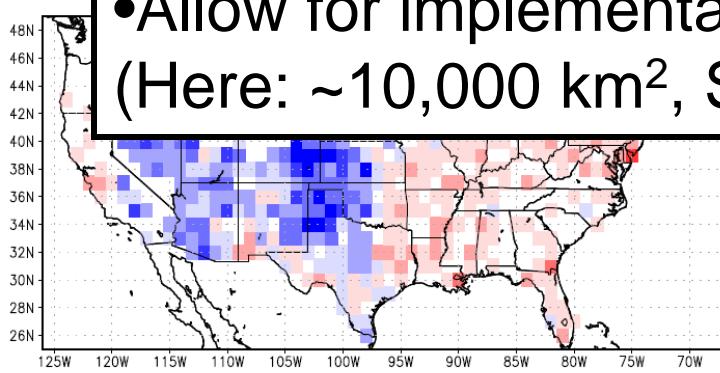


b) R²



SMAP will:

- Enhance correction in vegetated areas. (Here: X-band, SMAP: L-band)
- Allow for implementation at finer space scales. (Here: ~10,000 km², SMAP: 100 km²)





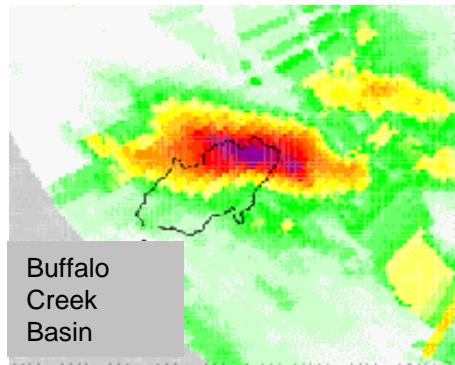
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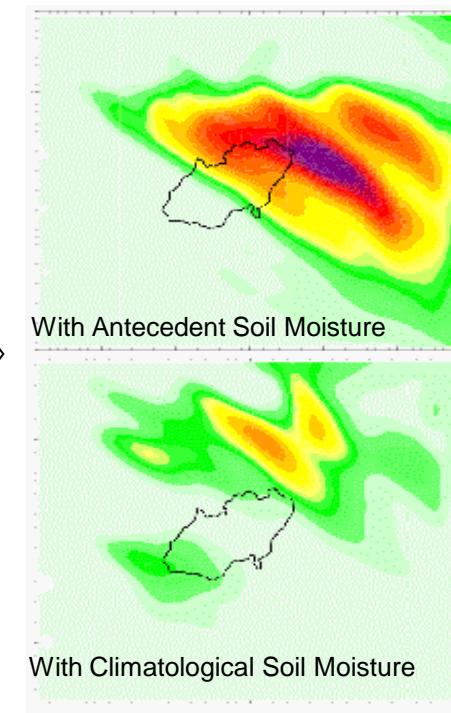
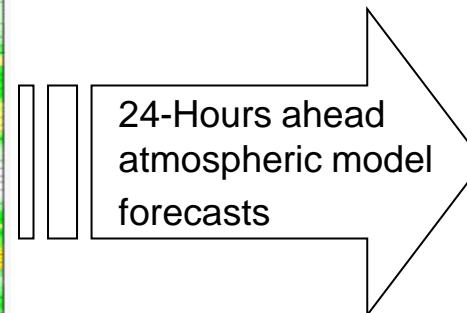
Prediction of Extreme Rainfall

Flash flood event near Fort Collins
July 13, 1996

Chen et al. (2001), JAS, 58, 3204-3223.



NEXRAD Observed Rainfall
0000Z to 0400Z 13/7/96

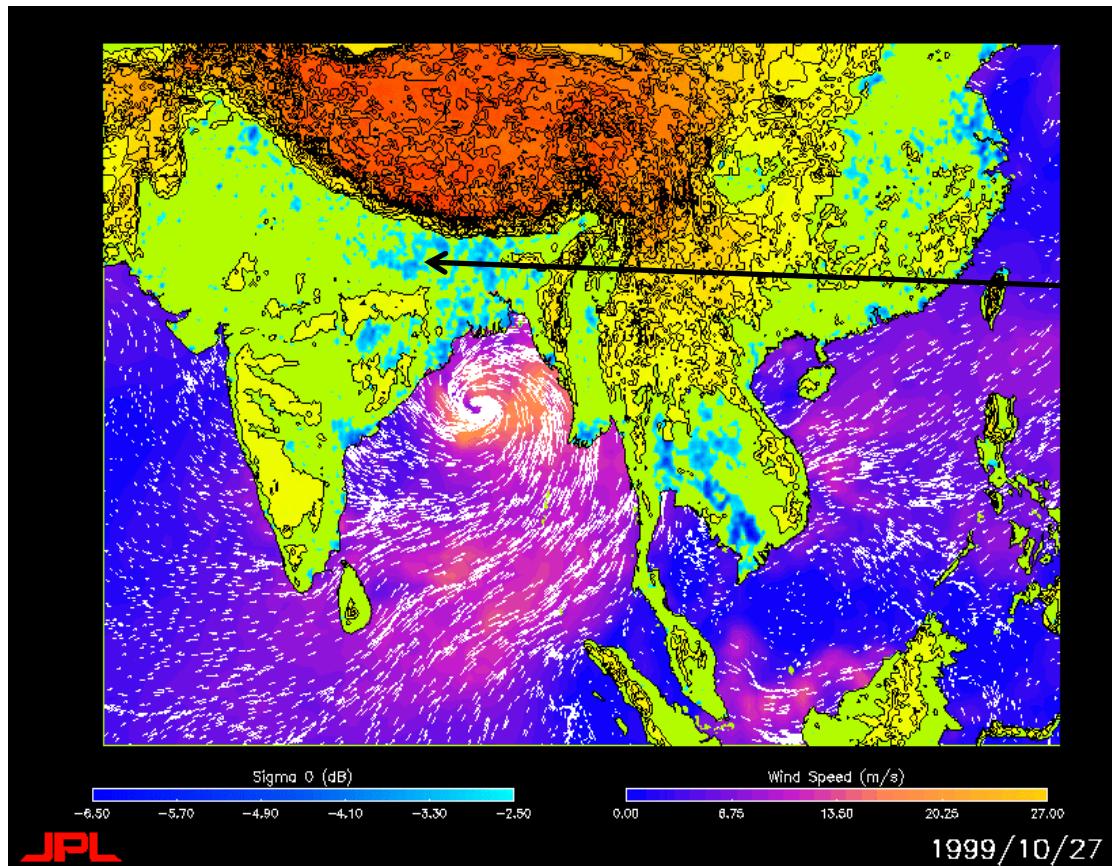




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Monitoring Inundation



Inundation detection using dual-polarization QuikSCAT backscatter data. Shades of blue on land represent inundation

[Form Son Nghiem, JPL]

$$\gamma = \frac{\sigma_{vv}}{\sigma_{hh}}$$

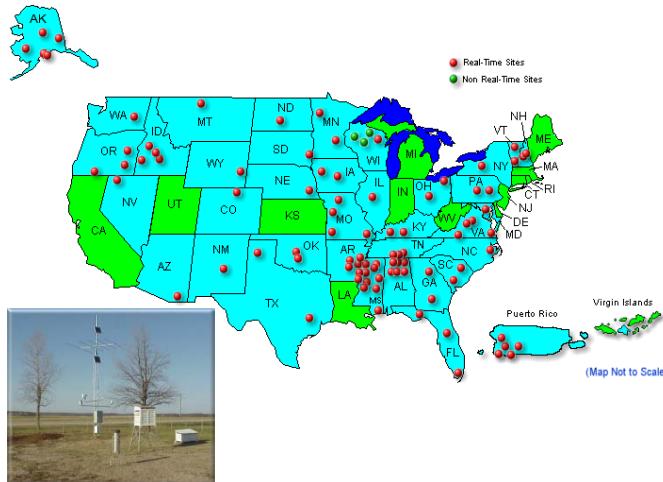
SMAP provides 3 km resolution dual-polarization radar data with 2-3 days revisit (all-weather and regardless of illumination)



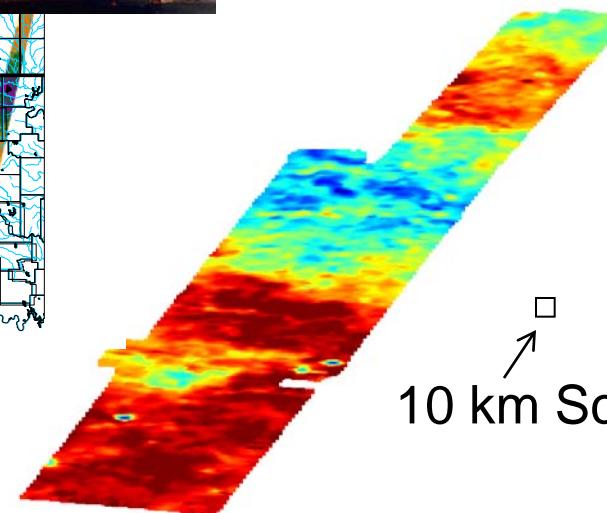
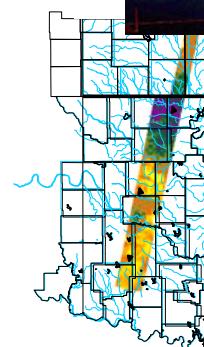
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In situ Soil Moisture Network Coverage:Adequate?

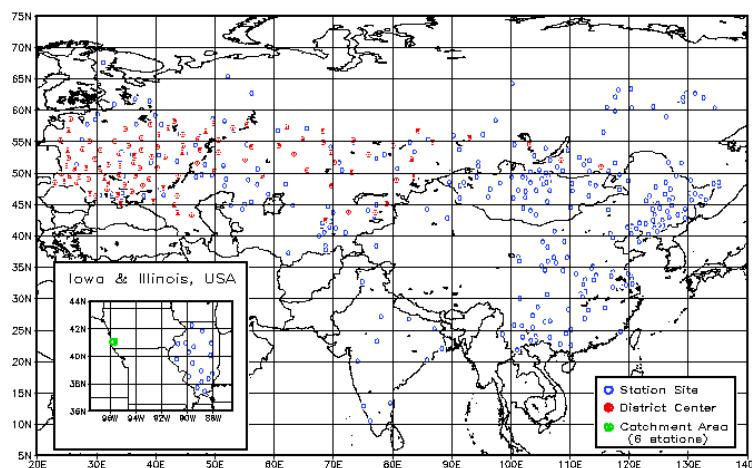


An airborne campaign
US SGP



10 km Scale

Significant spatial variability between
point measurements !





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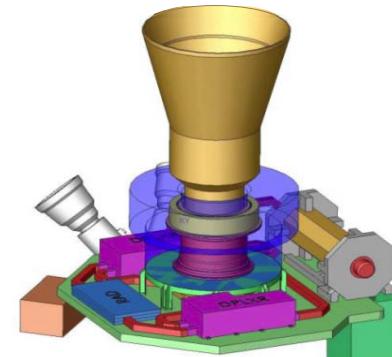
SMAP Mission Concept

May 2010 | Volume 98 | Number 5

Proceedings OF THE IEEE

The cover of the IEEE Special Issue on Satellite Remote Sensing features a satellite in orbit above Earth, with a large parabolic antenna and solar panels. A beam of light is shown originating from the satellite and pointing down towards a desert landscape on Earth. The title "SPECIAL ISSUE" is at the top right, followed by "SATELLITE REMOTE SENSING: Monitoring Water, Carbon & Global Climate Change". Other text on the cover includes "Point of View: Network Coding", "Electrical Engineering Hall of Fame: Wilmer L. Barrow", and the IEEE logo.

- L-band unfocused SAR and radiometer system, offset-fed 6 m light-weight deployable mesh reflector. Shared feed for
 - 1.26 GHz dual-pol Radar at 1-3 km (30% nadir gap)
 - 1.4 GHz polarimetric Radiometer at 40 km
- Conical scan, fixed incidence angle across swath
- Contiguous 1000 km swath with 2-3 days revisit
- Sun-synchronous 6am/6pm orbit (680 km)
- Launch November 2014
- Mission duration 3 years





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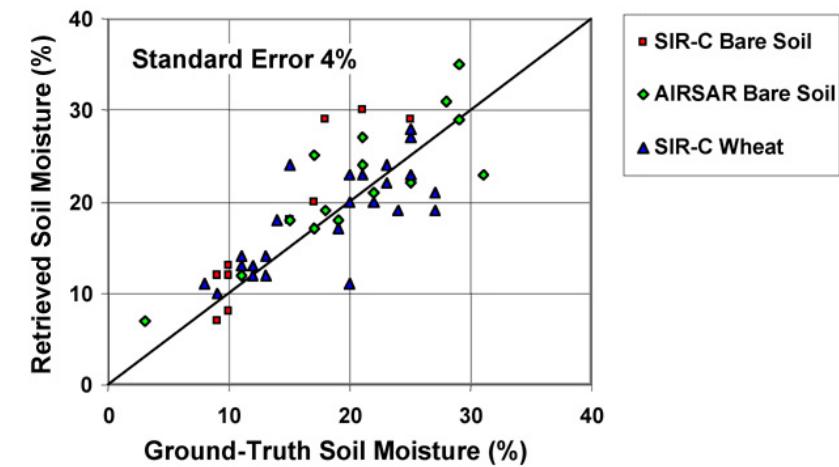
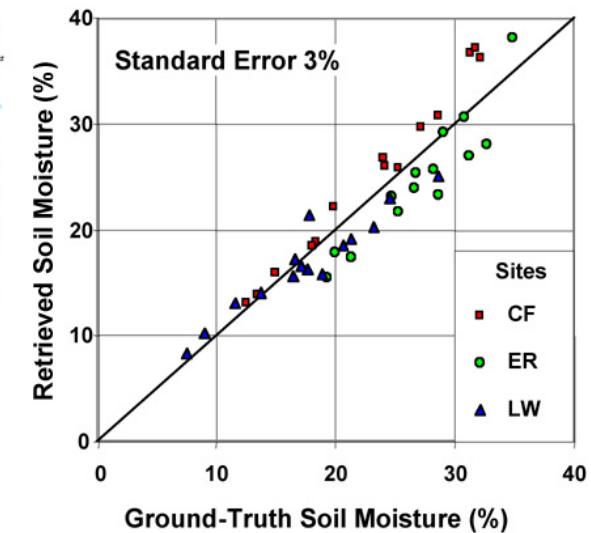
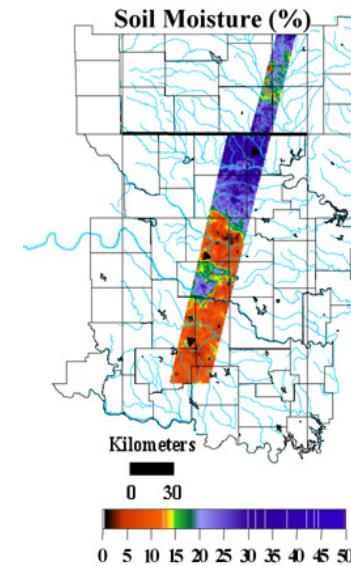
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

L-band Active/Passive Assessment

- Soil moisture retrieval algorithms are derived from a long heritage of microwave modeling and field experiments

MacHydro'90, Monsoon'91, Washita92, Washita94, SGP97, SGP99, SMEX02, SMEX03, SMEX04, SMEX05, CLASIC, SMAPVEX08, CanEx10

- **Radiometer** - High accuracy (less influenced by roughness and vegetation) but coarser spatial resolution (40 km)
- **Radar** - High spatial resolution (1-3 km) but more sensitive to surface roughness and vegetation
- **Combined Radar-Radiometer** product provides optimal blend of resolution and accuracy to meet science objectives





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SMAP Data Products

Product	Short Description	Resolution	Latency	
L1A_S0	Radar raw data in time order	–	12 hours	Instrument Data
L1A_TB	Radiometer raw data in time order	–	12 hours	
L1B_S0_LoRes	Low resolution radar σ_o in time order	5x30 km	12 hours	
L1B_TB	Radiometer T_B in time order	36x47 km	12 hours	
L1C_S0_HiRes	High resolution radar σ_o	1-3 km	12 hours	
L1C_TB	Radiometer T_B	36 km	12 hours	
L2_SM_A	Soil moisture (radar)	3 km	24 hours	Science Data (Half-Orbit)
L2_SM_P	Soil moisture (radiometer)	36 km	24 hours	
L2_SM_A/P	Soil moisture (radar/radiometer)	9 km	24 hours	
L3_F/T_A	Freeze/thaw state (radar)	3 km	36 hours	Science Data (Daily Composite)
L3_SM_P	Soil moisture (radiometer)	36 km	36 hours	
L3_SM_A/P	Soil moisture (radar/radiometer)	9 km	36 hours	
L4_SM	Soil moisture (surface & root zone)	9 km	7 days	Science Value-Added
L4_C	Carbon net ecosystem exchange (NEE)	9 km	14 days	

Interested in joining the SMAP Working Group?

- Sign up at <http://smap.jpl.nasa.gov/science/wgroups>
- 1. Algorithms Working Group (AWG)
- 2. Calibration & Validation Working Group (CVWG)
- 3. Radio-Frequency Interference Working Group (RFIWG)
- 4. Applications Working Group (ApWG)

A screenshot of a Mozilla Firefox browser window displaying the SMAP Applications page. The address bar shows the URL <http://smap.jpl.nasa.gov/applications/>. The page header features the NASA Jet Propulsion Laboratory logo and the text "Jet Propulsion Laboratory California Institute of Technology". Below the header, a banner image shows a satellite in space with the text "Mapping soil moisture and freeze/thaw state from space". The main content area is titled "APPLICATIONS" and includes a "Applications Overview" section. A sidebar on the left lists navigation links such as Home, Mission Imperative, Science, Applications, Links, Mission Description, and Instrument. The overall theme is dark blue with white and yellow text.

Applications - Mozilla Firefox

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http://smap.jpl.nasa.gov/applications/

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Applications

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Mapping soil moisture and freeze/thaw state from space

SMAP
Soil Moisture Active & Passive

Search Go

APPLICATIONS

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Applications Overview

The SMAP mission has the potential to enable a diverse range of applications including drought and flood guidance, agricultural productivity estimation, weather forecasting, climate predictions, human health risk, and defense systems. Applications across agencies are a unique feature of SMAP.

The [SMAP Applications Working Group](#) coordinates applications activities for the mission. The working group recently held the [1st SMAP Applications Workshop](#), at the NOAA Science Center, Silver Spring, MD, September 9-10, 2009.

Weather & Climate Forecasting: Soil moisture variations affect the evolution of weather and climate over continental regions. Initialization of numerical weather prediction and seasonal climate models with accurate soil moisture information enhances their prediction skills and extends their skillful lead times. Improved